Articles

The Causes of Deforestation in Developing Countries

Julia C. Allen* and Douglas F. Barnes†

*Departments of Geography and Environmental Studies, University of California, Santa Barbara, CA 93106
†World Bank, Washington, D.C. 20433

Abstract. Developing nations are faced with a two-edged sword in the field of energy. On the one hand the rising price of oil has reduced the potential for fossil fuel energy and eroded foreign exchange reserves in oil-importing countries. At the same time deforestation may be causing increased prices or shortages of fuels such as fuelwood and charcoal. This paper reviews the most recent and sometimes controversial estimates of deforestation in developing countries and analyzes the relationship between deforestation and its probable causes. Three recent estimates of the rate of deforestation in developing countries between 1968 and 1978 are compared using rank order correlation. Two of the estimates, of closed forest and moist tropical forest, are in significant agreement but differ from a third estimate that includes open woodland and regenerating forest. Agreement is strong among all three sources for a restricted group of countries. A cross-national analysis confirms the most frequently cited causes of deforestation. Deforestation from 1968–78 in 39 countries in Africa, Latin America, and Asia is significantly related to the rate of population growth over the period and to wood fuels production and wood exports in 1968; it is indirectly related to agricultural expansion and not related to the growth of per capita GNP. Results indicate that in the short term, deforestation is due to population growth and agricultural expansion, aggravated over the long term by wood harvesting for fuel and export.

Key Words: deforestation, wood energy, developing countries, fuelwood, charcoal, agricultural expansion, population growth.

DEFORESTATION has recently become a major concern for developing countries. Provocative studies on the subject have conveyed the impression that many developing countries are on the verge of being transformed into vast deserts and barren mountain watersheds (see Barney 1980; Eckholm 1975, 1982a, 1982b; Daniel and Kulasingan 1974; Gomez-Pompa, Vasques, and Guevara 1972; Hecht 1982; Myers 1980, 1982, 1983). At the same time other studies dismiss the extensive pessimism surrounding the topic of deforestation and conclude that there will be abundant forest resources in both the near and distant future (see Castle 1982; Clawson 1981; Sedjo n.d.; Simon 1981, 1982). The term deforestation has been used to describe changes in many different ecosystems, but wherever it occurs, deforestation affects a particular geographic area. Consequently, it is a cause for serious concern in the affected regions; the loss of forest cover can have adverse effects on the supply of wood fuels for household energy, soil and water resources, and the quality of rural life. In addition, if deforestation is widespread, it can have global repercussions: large-scale loss of forest area has been implicated in changes in wood supply, the hydrologic balance, genetic resources, and global cycles of carbon and other elements (Houghton et al. 1983; Myers and Myers 1982; Myers 1983; Nordin and Meade 1981; Woodwell et al. 1983a, 1983b).

Disagreement on the magnitude, causes, and consequences of deforestation is common (Fearnside 1982; Lugo and Brown 1982). Incommensurate definitions of forest area, including definitions that change over time, have made comparison of deforestation rates difficult. The disparities among estimates of the rate of deforestation cause large errors when these numbers

Annals of the Association of American Geographers, 75(2), 1985, pp. 163–184

are used in calculations of carbon dioxide levels and other global biogeochemical cycles (Houghton et al. 1983; Woodwell et al. 1983a, 1983b). Also, generalizations regarding the causes of deforestation have been hard to establish, partly because many studies have focused on specific problems or regions. There may be little apparent similarity, for example, between desertification in the Sahel and the degradation of forested mountainsides in Nepal, yet both are examples of deforestation.

This study reviews and compares the best recent estimates of deforestation and attempts to relate rates of deforestation to alleged causes and effects in developing countries. We provide no new evidence about deforestation in particular countries. Instead we use currently available data to derive policy recommendations regarding global deforestation and illustrate the limitations imposed on such a process by the scale and inherent uncertainty in the data.

According to all the best available evidence, deforestation is a real trend in almost all developing countries although the magnitude of the problem varies substantially. Despite the definitional problems, we have found a surprising amount of agreement among estimates of deforestation on a country-by-country basis and much similarity in the rank ordering of countries according to their rates of deforestation. Furthermore, the results of a cross-national analysis of the causes of deforestation in developing countries generally confirm the most frequently cited causes of deforestation. Rapid population growth, expansion of cropland, and intensive harvesting of forests for fuelwood and wood exports contribute to deforestation in different areas of the world although the time lags between causes and effects vary dramatically. On the other hand, the socioeconomic and ecological effects of deforestation are varied and often unknown. Deforestation may have destructive or constructive consequences depending upon ecological conditions, extent of economic development, and many other factors (Allen 1983).

Concern About Deforestation

Deforestation has long been the imputed cause of ecological degradation in Europe, the Middle East, and Asia (Marsh 1874; von Wissman et al. 1956; Thirgood 1981; Thomas 1956). Awareness of the deforestation problem in developing countries emerged in the early 1970s when several studies illustrated the severity of environmental damage and wood shortages attributable to deforestation. These first studies on the subject included graphic descriptions of erosion in mountainous regions and first-hand accounts of desertification in the semi-arid tropics (Daniel and Kulasingan 1974; Eckholm 1975, 1976). Other authors focused on the losses of species and of unique ecosystems that result from tropical deforestation (Gomez-Pompa, Vasques, and Guevara 1972; Myers 1976, 1982; World Ecological Areas Programme 1980). More recent studies have reiterated and systematized these basic arguments, and there is substantial agreement that the degree of impact varies with the amount of forest area lost (Pires and Prance 1977; Prance 1977, 1982). Consequently the argument regarding the severity of deforestation has evolved into one regarding the extent of deforestation.

In an attempt to resolve some of the uncertainty in 1979 the U.S. government commissioned a task force to prepare an overview of the magnitude of deforestation and related issues (U.S. Interagency Task Force on Tropical Forests 1980). The Task Force (1980, 2) found that tropical forests are disappearing at an alarming rate as a result of intense pressures from populations seeking food, energy, wood, and shelter. According to the Task Force report, the consequences of deforestation are rising prices, floods, siltation, and desertification. Projecting the present trends in forest area, the Task Force (1980, 15) concluded that the world's tropical forests outside of central Africa and the Amazon basin would be ''nothing but scattered remnants'' by the year 2025.

At about the same time as this report, Myers (1980) completed for the National Academy of Sciences a report estimating the extent of deforestation in moist tropical forests over the last several decades. Myers (1980, 6–7, 173) emphasized the unreliability of deforestation estimates and pointed out that deforestation estimates for many countries are based on educated guesses of doubtful validity. In some countries remote sensing data are available, but these are subject to other problems discussed below. Although he qualified all the data presented in his report, Myers concluded that tropical moist forests are undergoing extensive conversion to degraded forest or to other uses.

Most recently, in early 1981 the Forest Re-

sources Division of the U.N. Food and Agricultural Organization (FAO) made available the results of an inventory of tropical forest area in Africa, Asia, and Latin America (FAO/UNEP 1982a, 1982b, 1982c). These estimates, which synthesize unpublished information but are not a new forest inventory, suggest that deforestation, until recently confined to Africa and Asia, is now a significant and increasing trend also in Latin America. Figure 1 shows the average annual rate of deforestation of all developing countries from 1976–80 as reported in FAO/UNEP (1982a, 1982b, 1982c). Apart from a group of small countries with anomalously high rates, deforestation appears to be progressing most rapidly in countries with forest areas near the median (note log scale).

These reports of the impacts of deforestation and estimates of trends in developing countries' forest areas have raised concern about diminishing forests (Myers 1982). Recent projections of current deforestation trends to the year 2000 accentuate the severity of the problem. Projections in the Global 2000 report (Barney 1980, 117–20) indicate that if current trends continue, between 1958 and 2000 world forest area will decrease by one-third. Most of this deforestation will occur in the developing countries, where forests are projected to decline at 3–6 percent annually in some nations, and even faster in others. Based on the FAO/UNEP study, projections by the World Bank suggest that as a consequence of deforestation, wood fuel supplies will be inadequate to meet demand long before the year 2000 in many nations (Spears 1980; World Bank 1980b, 125). To meet world demand for fuelwood at the turn of the century would necessitate the planting of more than 50 million hectares of trees just for fuelwood; this represents a five-fold increase in the world's current rate of tree planting for all uses (World Bank 1980c, 39).

Taken together, these reports indicate that deforestation is a phenomenon with potentially serious consequences. The severity of the deforestation problem depends upon the width of the error bands around projections of future conditions. There are two potential sources of error in projections of deforestation trends: errors in estimated present rates of deforestation and errors of omission of mitigating circumstances that could counterbalance present trends. The latter include factors that augment resources (Clawson 1981; Simon 1982) and the ability of natural systems to recover following disturbance (Castle 1982; Uhl 1982; West, Shugart, and Botkin 1981).

Errors in present estimates of deforestation rates are due to the shortness of the record of observations of forest area on an appropriate scale and the limited accuracy of currently practicable technology for forest inventory. Only in recent years have data on forest area been collected specifically to estimate deforestation (Myers 1980; FAO 1978a; FAO/UNEP 1982a, 1982b, 1982c). These publications are a composite of forest inventories that have used varied methods and data sources, including official statistics, forest inventories, manual interpretation of aerial photographs, or satellite imagery. Statistics compiled in this way are based on (1) subjective distinctions between vegetation types (in the field) or patterns (in photographs and imagery) or (2) objective distinctions between spectral reflectance patterns presumed to be correlated with vegetation types (in satellite imagery). No global survey of deforestation based on objective methods of analysis of Landsat imagery has yet been conducted. The cost for such a project, which would involve a sampling program designed to reduce levels of uncertainty surrounding current deforestation rates to ±25 percent, has been estimated at \$4 to \$7 million for data and imagery analysis alone (Woodwell et al. 1983a).

Because of the controversy surrounding the estimates of deforestation, we have reviewed in detail the most recent and reliable evidence for deforestation in developing countries.

Process and Extent of Deforestation

In order to explore the relationship between deforestation and its causes it was necessary to identify those areas of the world that are most seriously affected by deforestation. This requires a definition of the process of deforestation and a reliable measure of its progress on the global, continental, national, and local levels.

The initial working definition of deforestation was a change in forest area over time. But forest area is an ambiguous concept. At the global scale, estimates of forest area vary widely with no obvious trend. Table 1 and Figure 2 show the available estimates of world forest area, arranged chronologically by source. The observations are randomly distributed around the mean of 4,160 million hectares. Thus, global es-

Figure 1. Deforestation by country as a function of forest area. Compiled from data in FAO/UNEP (1982a, 1982b, 1982c).

timates of forest area show no trend over time, especially not a downward trend, nor do the continent-by-continent estimates of closed forest and forestland in Africa, Asia, or Latin America shown in Figure 3 show a downward trend. In fact, forestland in Africa and Latin America appears to be increasing. These data probably are not very reliable indicators of deforestation, however, because they combine estimates from different sources, include different countries, and cover only a seven-year period. Also, they may reflect increasing accuracy, as a result of rising interest in estimating the forest resource base, and not actual trends in forest area in these regions.

The wide range of global and continent estimates (from 2,392 to 6,050 million hectares) is no doubt due to different definitions of forest. Many different woody formations may be included in an estimate of forest area. To clarify the confusion this sometimes causes, Figure 4 shows the different vegetation formations that occur with different levels of rainfall and human intervention (Huntley and Walker 1982; Richards 1964; West, Shugart, and Botkin 1981). This chart is not all-inclusive, but for the purposes of this study it illustrates the formations that constitute the two most frequently used terms for forest area: closed forest and forestland. Closed forest includes natural and managed closed forest of all types and forest plantations, and is distinguished by a high percentage of tree canopy cover, by generally high precipitation, and by low grass cover. Forestland, a broader category, includes closed forest and other woody formations such as woodland, shifting cultivation, or agroforestry that occur under mean to median rainfall with less tree canopy cover and higher grass cover. Note that over time, an area may move from the upper left to the lower right of the diagram with increasing human disturbance or decreasing effective precipitation. Any such move may be interpreted as deforestation.

In the most complete surveys, deforestation has been defined in several distinct ways: (1) as the transformation of primary closed forest to any other formation (Myers 1980); (2) as the loss of any kind of closed forest (FAO/UNEP 1982a, 1982b, 1982c); or (3) as the loss of forestland (FAO 1978a, 1980a). In practice, however, it is rarely possible to distinguish primary closed forest from old secondary forest partly because variable physical factors produce great variability in forest floristic composition and growth rates (West, Shugart, and Botkin 1981). Consequently, the distinction between natural closed forest and other closed forests breaks down somewhat. These definitions of forest area should be kept in mind when examining the country-by-country estimates of deforestation in Table 3.

Only three sources (FAO 1978a, 1980a; FAO/UNEP 1982a, 1982b, 1982c; Myers 1980) use consistent definitions to monitor trends in forest area on a country-by-country basis for four years or more. Because the FAO *Production Yearbook*'s definition is the most comprehensive (it includes open woodland, wooded savanna, and degraded forests), it has been used in studies of global carbon cycling (Houghton et al. 1983; Woodwell et al. 1983b). The average annual change in forest area as defined by each of these three sources is expressed as a percent of the forest area in the base years in Table 2. The FAO *Production Yearbook* measures deforestation as the change in forestland area over the period 1968–78; the FAO/UNEP study measures deforestation as the change in natural closed forest area over the period 1976–80; and Myers measures deforestation as the conversion of moist tropical forest to other uses over various periods (see notes to Table 2). Myers attempts to account for the imputed greater value of species-rich ecosystems by restricting his definition to tropical moist forest. The FAO/UNEP study attempts to account for the stock of woody biomass by distinguishing natural closed forest from natural open woodland, plantations, and woody fallow. The FAO *Production Yearbook* lumps all woody formations including woody fallows in a single category.

The estimates in Table 2 reveal several interesting trends. First, all three sources show the average rate of estimated change to be negative: on average, regardless of how they are defined, forests in developing countries are declining. The average rate of estimated tropical moist forest conversion is highest (−0.84 percent per year), followed by the average rate of recent change in closed forest area (−0.54 percent per year). Second, forestland, the broadest category, shows the least average rate of estimated change (−0.25 percent per year). Most developing countries are losing forestland, and all developing countries show a net loss of natural closed forest area. Third, all three sources indicate that on average deforestation is occurring at rates of less than 1 percent of forest area per

Table 1. Estimates of Forest Area of Africa, Asia, Latin America, and the World. Figures are in Million Hectares and Are Arranged Chronologically by Source

Year		Source	World	Africa[g]	Asia[h]	Latin America[j]
1961	(1)[a]	Weck and Wiebecke, in Lieth 1979	2,477	—[b]	—	—
1963	(2)	FAO 1963	4,126	—	—	—
1965	(3)	FAO 1966	4,138	—	—	—
1971	(4)	Bazilevich, Rodin, and Rozov 1971	5,290	—	—	—
	(5)	Bruning 1971	3,590	—	—	—
	(6)	Whittaker and Woodwell 1971	5,000	—	—	—
1972	(7)	Lieth 1972	5,000	—	—	—
1973	(8)	Whittaker and Likens 1973	4,850	—	—	—
1974	(9)	Persson 1974[c]	4,030	190–760	400–460	590–742
	(10)	Bruning 1975	4,150	—	—	—
	(11)	Windhorst 1974	2,393	—	—	—
1975	(12)	Olson 1975	4,800	—	—	—
	(13)	Eckholm 1975	2,657	—	—	—
		Lanly and Clement 1979[d]	—	204	303	660
	(14)	Lieth and Whittaker 1975	5,000	—	—	—
1976		Sommer 1976[e]	—	175–334	254–417	506–964
1978	(15)	Eyre 1978	6,050	—	—	—
	(16)	Ross-Sheriff 1980	2,563	—	—	—
	(17)	Openshaw 1978	3,712	—	—	—
1979	(18)	Steele 1979	3,799	—	—	—
	(19)	FAO 1980a	4,056	—	—	—
1980		Myers 1980	—	—	—	—
		FAO/UNEP 1982a, 1982b, 1982c[f]	—	217–312	305–455	679–1,212

[a] Numbers in parentheses correspond to estimates plotted in Figure 2.

[b] Blanks indicate figures not available.

[c] In the Persson estimates, the smaller figure refers to closed forest area, and the larger figure to forestland area.

[d] The Lanly and Clement estimates refer to area of natural closed forests, including hardwood and softwood, productive and unproductive.

[e] In the Sommer estimates, the smaller figures refer to moist forest area, and the larger to forestland area.

[f] In the FAO/UNEP estimates, the smaller figure refers to area of closed broad-leaf coniferous and bamboo forests, and the larger figure to area of natural woody vegetation, including closed and open forest, forest fallows, and shrub vegetation.

[g] Each estimate for Africa includes different countries. The Sommer estimate (23 countries) includes Kenya, Madagascar, Mauritius, Reunion, Tanzania, Uganda, Cameroon, Central African Republic, Congo, Equatorial Guinea, Gabon, Zaire, Angola, and Cabinda, Benin, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Nigeria, Senegal, Sierra Leone, and Togo.

The Lanly estimate (43 countries) includes all of the above and Cape Verde, Chad, the Gambia, Mali, Mauritania, Niger, Upper Volta, Sao Tome and Principe, Burundi, Djibouti, Ethiopia, Malawi, Mozambique, Rwanda, Somalia, the Sudan, Zambia, Botswana, Namibia, and Zimbabwe.

The FAO/UNEP estimate (37 countries) includes all of the above except Mauritius, Reunion, Cape Verde, Mauritania, Sao Tome and Principe, and Djibouti.

The Persson estimate (56 countries) includes all of the above and Algeria, British Indian Oceans Territory, Cape Verde, Comoro Islands, Egypt, French Territory of Afars and Issacs, Lesotho, Libya, Mauritius, Morocco, Reunion, St. Helena, Tristan de Cunha, Sao Tome and Principe, Seychelles, South Africa, Spanish Sahara, and Swaziland.

[h] Each estimate for Asia includes different countries. The Sommer estimate (18 countries) includes tropical Australia, British Solomon Islands, Fiji, Hawaii, New Caledonia, Papua New Guinea, Brunei, Burma, Cambodia, Indonesia, Laos, Malaysia, Philippines, Thailand, Vietnam, Bangladesh, India, and Sri Lanka.

The Lanly estimate (23 countries) includes all of the above except the Bhutan, Nepal, Pakistan, New Hebrides, Western Samoa, South Korea, and Taiwan, and excludes tropical Australia and Hawaii.

The FAO/UNEP estimate (16 countries) excludes British Solomon Islands, Fiji, New Caledonia, New Hebrides, Western Samoa, South Korea, and Taiwan.

The Persson estimate (45 countries) includes all of the above and Afghanistan, Bahrain, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Muscat and Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, Yemen Arab Republic, Yemen PDR, Japan, Khmer Republic, North Korea, South Korea, Maldives, Mongolia, Portuguese Timor, Ryukyu Islands, Sikkim, and Singapore. It excludes the Solomon Islands, Fiji, New Caledonia, New Hebrides, and Western Samoa.

[j] Each estimate for Latin America includes different countries. The Sommer estimate (24 countries) includes tropical Argentina, Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Paraguay, Peru, Surinam, Venezuela, Belize, Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Honduras, Jamaica, tropical Mexico, Nicaragua, Panama, and Trinidad and Tobago.

The FAO/UNEP estimate (24 countries) includes all of the above except Argentina and includes the nontropical part of Mexico.

The Lanly estimate (30 countries) includes all of the above and the Bahamas, Guadeloupe, Martinique, Chile, Uruguay, and the nontropical part of Argentina.

The Persson estimate (50 countries) includes all of the above and Antigua, the Bahamas, Barbados, Bermuda, Cayman Islands, Dominica, Grenada, Guadeloupe, Monserrat, Netherlands Antilles, Panama Canal Zone, Puerto Rico, St. Kitts-Nevis-Anguilla, St. Lucia, St. Pierre and Miquelon, St. Vincent, Turks and Caicos Islands, Virgin Islands (U.S. and U.K.) and the Falkland Islands.

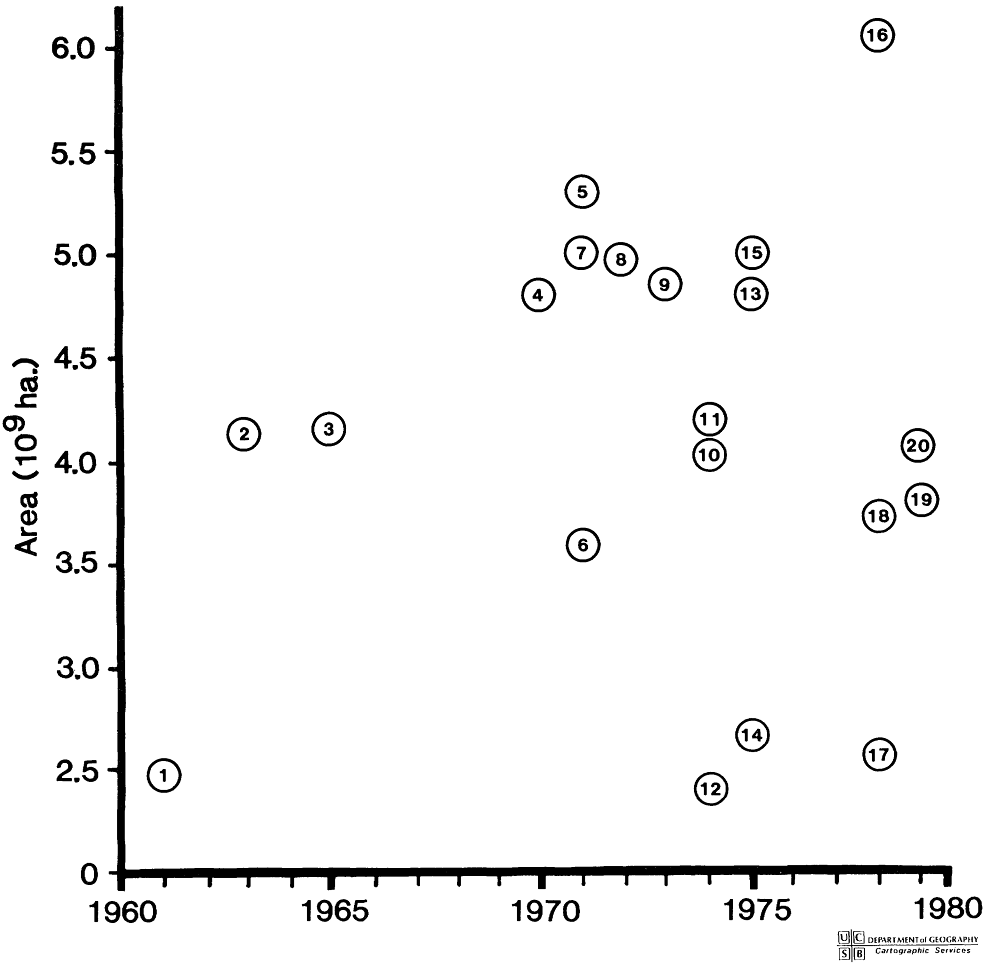


Figure 2. Estimates of world forest area. Area of closed forest or forestland as defined in the text and in Figure 4. Estimates are arranged chronologically, and circled numbers refer to sources listed in Table 1.

year (FAO 1980a; FAO/UNEP 1982a, 1982b, 1982c) or 1–2 percent of forest area per year (Myers 1980) in Africa, Latin America, and Asia (see the weighted averages in Table 2). Deforestation rates in Table 2 do not take into account changes in forest plantation area, but plantations cover less than 2 percent of the area of natural closed forests in Africa, Asia, and Latin America (FAO/UNEP 1982a, 1982b, 1982c; Lanly and Clement 1979).

Although on average there is a downward trend in forest area, the rankings and weighted averages shown in Table 2 indicate that there is some disagreement among sources on the trends for continents and for individual countries. This partly reflects the different definitions of forest used in the three data sets. It is not clear, therefore, which data set is most appropriate for analyzing the causes of deforestation. In order to determine the extent of agreement among the three sources, we examined the rank order correlations among the three lists arranged by deforestation rate. Rank order correlation was chosen as the appropriate statistical technique because only the ranks, not the deforestation rates themselves, are comparable given the different definitions of forest area. The results of this analysis are shown in Table 3.

FAO/UNEP and Myers both measure the change in natural closed forest area. Thus one would expect higher rank order correlation between FAO/UNEP and Myers than between either of them and the FAO *Production Yearbook*. The high rank order correlation coefficient (r = 0.641) in row 5 of Table 3 confirms the expected agreement in rankings of loss of closed forest.

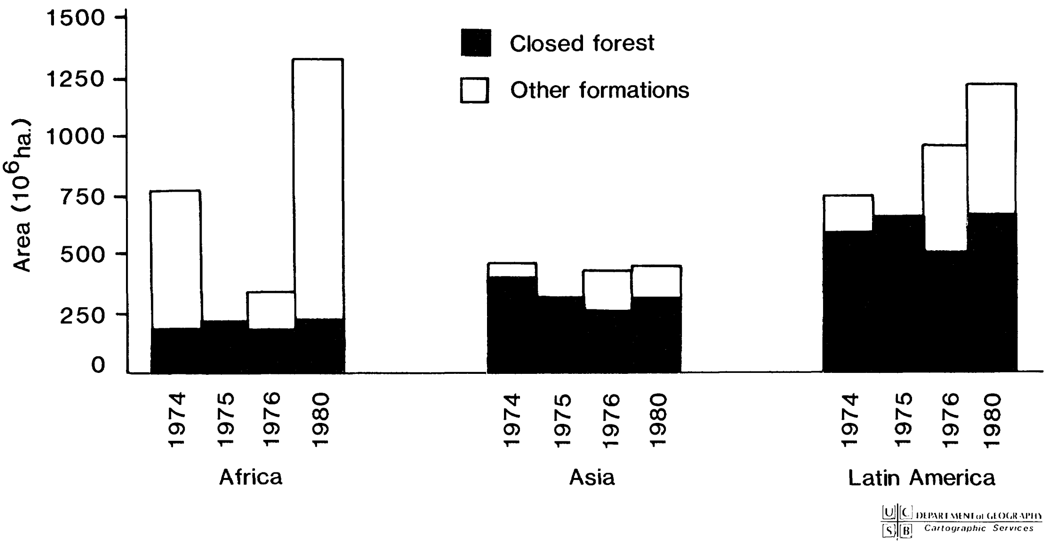
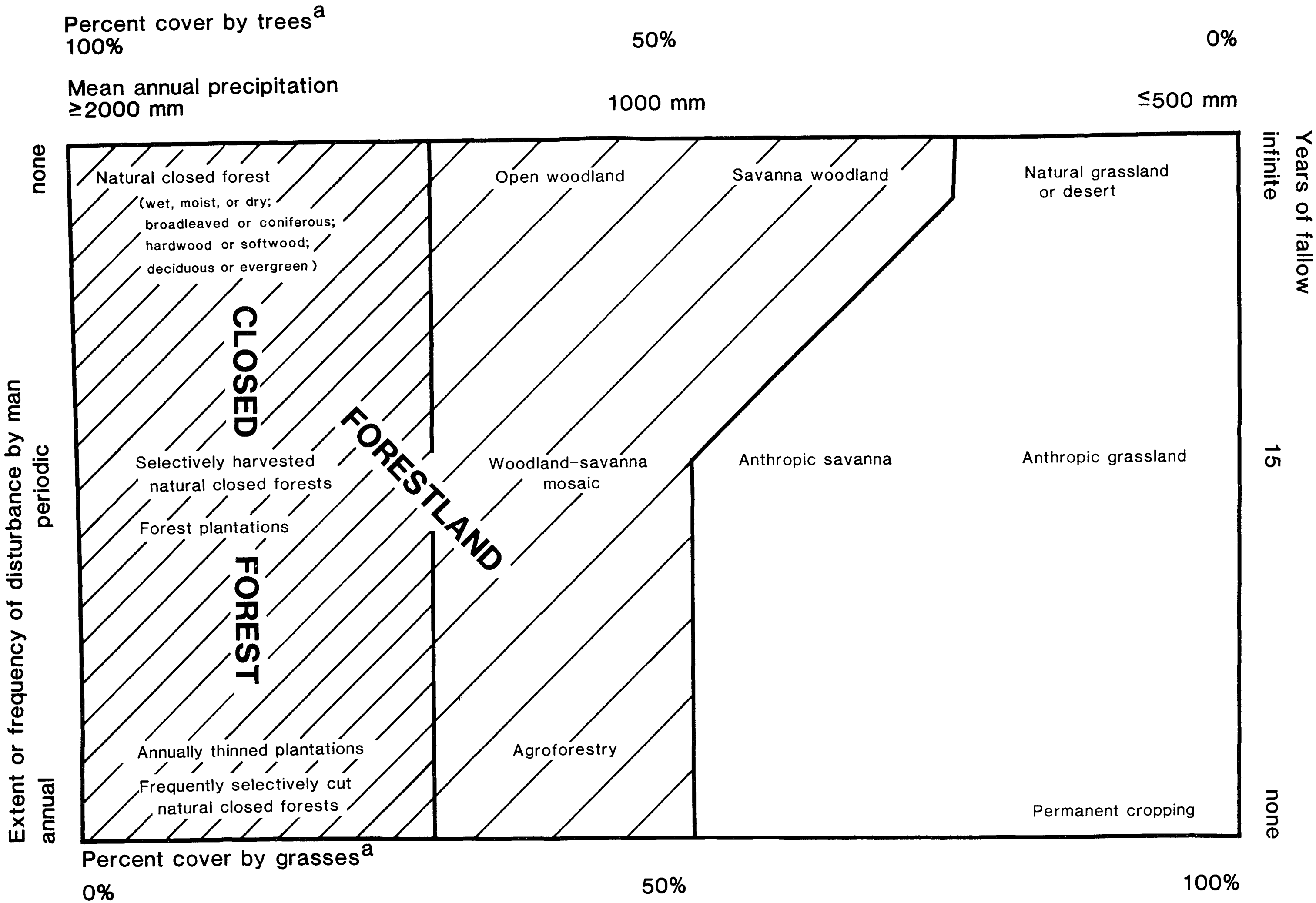


Figure 3. Estimates of forest area in Africa, Asia, and Latin America. Area of closed forest or other vegetation formations as defined in the text and in Figure 4. Estimates for 1974 are taken from Persson (1974), for 1975 from Lanly and Clement (1979), for 1976 from Sommer (1976), and for 1980 from FAO/UNEP (1982a, 1982b, 1982c).

The low coefficients (r = 0.112, 0.124) in row 1 of Table 3 confirm the expected lack of agreement between rankings of deforestation based on forestland and those based on closed forest.

If the FAO *Yearbook* data convey a picture of deforestation that is dramatically different from that portrayed by the other two sources, use of the *Yearbook* data in an analysis of causes of deforestation could seriously misrepresent the deforestation picture. There is no obvious systematic explanation for the disagreement between the FAO and the other two sources of deforestation estimates. A number of possible causes of discrepancy were explored by selective removal of certain countries and examination of the improvement, if any, in the agreement among the modified lists. The coefficients in row 2 of Table 3 show that the removal of countries that reported no change in forest area or had unreliable data according to FAO did not improve the agreement among sources. The coefficients in row 3 of Table 3 show that removal of the Latin American countries does not improve the agreement either; the lack of agreement was similar for all continents tested separately. As would be expected, the coefficients in row 4 show that removal of 14 outliers greatly improved the agreement among the estimates. For more than two-thirds of the countries in the sample, the FAO *Yearbook*'s implicit definition of deforestation as loss of forestland seems to capture the relative severity of losses in closed forest area. The disagreement does not, therefore, seem to warrant either the exclusion of some countries or the use of more than one source of deforestation estimates in the analysis of causes of deforestation.

Because the FAO *Production Yearbook* (1978a, 1980a) data are available for more countries and for a longer time period than are the FAO/UNEP (1982a, 1982b, 1982c) data, the FAO *Yearbook* data were used in this analysis. The countries that were included in the sample are indicated by an asterisk in Table 2. The rank order analysis in no way influenced the selection of countries for the cross-national analysis of causes of deforestation described below, and in fact many of the countries on which there were divergent rankings were included in the study. Moreover, the FAO *Yearbook* data were used in our analysis because the definition of forestland included many vegetation formations that, although not forests in the strictest sense, provide wood and other products important to people in developing countries. The disappearance of these other formations along with closed forests represents a transformation of the environment on which local people depend. The broader concept of deforestation as a loss of forestland (i.e., the FAO *Production Yearbook* data) more ade-



[a]Percent cover by grasses and by trees may sum to more than 100.

Figure 4. Vegetation formations as a function of climate and human intervention.

Table 2. Deforestation by Country According to Three Different Sources

Country	(1) FAO Yearbook (1980a)		(2) FAO/UNEP (1982a, 1982b, 1982c)		(3) Myers (1980)	
	Rank	Annual percent change[c]	Rank	Annual percent change[d]	Rank	Annual percent change[e]
*Ivory Coast[b]	1	−3.70	1	−5.40	1	−5.3[f]
*Haiti	2	−3.10	4	−3.20	—[a]	—
*Togo	3	−2.40	27	−0.64	—	—
*Philippines	4	−2.20	22	−1.02	8.5	−1.25[g]
Swaziland	5	−1.90	—	—	—	—
*Sri Lanka	6	−1.80	18	−1.89	5	−1.8[h]
*Liberia	7	−1.66	14	−1.89	6	−1.4[j]
Niger	8	−1.61	—	—	—	—
*Upper Volta	9	−1.56	—	—	—	—
*Rwanda	10	−1.46	10	−2.13	—	—
Brunei	11	−1.40	12	−1.99	—	—
*Ecuador	12	−1.14	13	−1.94	—	—
*Somalia	13	−0.94	32	−0.22	—	—
*Congo	14	−0.90	36	−0.10	—	—
*Mexico	15	−0.78	20	−1.09	—	—
*Malaysia	16	−0.75	21	−1.05	7	−1.3[k]
*Thailand	17	−0.54	6	−3.15	2	−4.3[m]
Afghanistan	18	−0.50	—	—	—	—
Vietnam	19	−0.46	25	−0.71	—	—
*Bolivia	20	−0.44	34	−0.14	—	—
Yemen PDR	21	−0.39	—	—	—	—
*Costa Rica	22	−0.38	5	−3.19	—	—
Sierra Leone	23	−0.36	24	−0.75	—	—
Belize	24	−0.34	26	−0.65	—	—
Surinam	25	−0.34	37	−0.02	—	−0.3[n]
*Brazil	26	−0.24	29	−0.40	11	−0.3[n]
*Zaire	27	−0.23	33	−0.15	—	−1.2[p]
*Indonesia	28	−0.11	28	−0.47	8.5	−1.2[p]
*Nepal	29	−0.11	2	−3.68	—	—
*Argentina	30	−0.09	—	—	—	—
*Zambia	31	−0.08	19	−1.26	—	—
*Paraguay	32	−0.08	3	−3.39	—	—
*South Korea	33	−0.08	—	—	—	—
*Bangladesh	34	−0.06	23	−0.83	10	−0.8[q]
*Jamaica	35	−0.01	11	−2.05	—	—
*Madagascar	36	−0.00	17	−1.50	4	−2.2[r]
*Benin	37	0.00	7.5	−2.83	—	—
Botswana	38	0.04	—	—	—	—
Kenya	39	0.05	16	−1.62	3	−2.6[s]
Uruguay	40	0.56	—	—	—	—
*Ethiopia	41	0.68	31	−0.23	—	—
*El Salvador	42	0.69	7.5	−2.83	—	—
*India	43	0.40	30	−0.28	—	—
Guinea	44	0.50	15	−1.64	—	—
China	45	0.60	—	—	—	—
Burundi	46	1.60	9	−0.24	—	—
Cuba	47	2.83	35	−0.13	—	—
Weighted average[t]						
All countries	—	−0.25	—	−0.54	—	−0.8
Africa	1	−0.51	3	−0.47	2	−1.4
Latin America	2	−0.29	2	−0.51	3	−0.3
Asia	3	0.05	1	−0.66	1	−1.5
Unweighted average[u]						
All countries	—	−0.53	—	−1.52	—	−2.0
Africa	1	−0.77	2	−1.52	1	−2.5
Latin America	2	−0.62	3	−1.46	3	−0.3
Asia	3	−0.21	1	−1.59	2	−1.8

quately captures the loss of forest utility to local populations.

Causes of Deforestation

Climate

Forests disappear naturally as a result of broad climate changes or catastrophes such as fire and landslides (Bennett 1979, 55; Margaris 1979, 123; Sommer 1976, 9; Winterbottom 1980, 5), but most change in forest area is the result of human activity. Changing social and economic systems have a dramatic effect on forests. Population—especially rapidly increasing or dense population—can increase demands for land and wood, eventually exceeding the carrying capacity of forests that are expected to supply wood fuels, food, and environmental protection for local people (Brokensha and Riley 1978, 26; Mnzava 1980, 8; Nkoma and Asman 1979, 5–6; Winterbottom 1980, 5; World Bank 1978, 18; Zambia Forest Department 1978, 6).

Agriculture

Growing populations need expanding food supplies, so forests are cleared by shifting cultivators for annual or permanent crops (Eckholm 1976, 39; Kartawinata 1979, 129–30; Mikesell 1960, 445; Powell 1978; Ranganathan 1979, 14–15). Rates of clearing are likely to be higher in countries where little or no progress has been made in agricultural productivity or where land productivity falls rapidly after the natural forest cover is removed (World Bank 1978, 18–19). Forests are disappearing both in countries still reliant on shifting cultivation and in those making the transition to permanent cropping patterns. Forests have also been cleared for resettlement schemes in countries like India and Brazil (Ranganathan 1979, 14–15). Subsidized cattle ranching has replaced large areas of rain forest in the Amazon basin (Fearnside 1982; Hecht 1982).

Logging

Other activities besides outright clearing affect the forest. Commercial logging operations deplete forest stocks (Eckholm 1976, 39; Powell 1978, 116). Regulated timber extraction should not permanently damage the forest (Schmithüsen 1976), but when it is not controlled, mechanized logging or even selective timber harvesting may severely alter the character of the forest

Table 2 continued:

Sources: Myers 1980; FAO 1966, 1980a; FAO/UNEP 1982a, 1982b, 1982c.

[a] Dash indicates data not available.

[b] Star indicates countries included in later regression analyses. Turkey, Morocco, Uganda, Burma, Dominican Republic, Guatemala, Nicaragua, and Panama are not listed in the table because of missing values, but are included in the later analyses.

[c] Average annual percent change in forests and woodland over the period 1968–78, using 1968 as a base year. Only complete removal of forest cover is measured. Forest and woodland refers to land under natural or planted stands of trees, whether productive or not, and includes land from which forests have been cleared but that will be reforested in the foreseeable future. Forests and woodland are not defined consistently in actual measurement practice by all countries or over all years.

[d] Average annual percent change in natural woody vegetation in the form of closed broadleaf, coniferous, or bamboo forest over the period 1976–80. Excludes forest plantations. Only complete removal of forest cover is measured. Includes tropical countries only.

[e] Average annual percent change in tropical moist forest over various periods. This measure includes all types of forest conversion, including logging. Tropical moist forest includes evergreen or partly evergreen forests, with or without some deciduous trees, but never completely leafless, up to 1,200m; forest savanna mosaic where forests are not confined to streamsides, and coastal savanna mosaic. According to the FAO Committee of Forest Development in the Tropics, interpretation of the term "tropical moist forest" should be left to individual countries (Sommer 1976, 6). Conversion of tropical moist forest can range from marginal modification to fundamental transformation (Myers 1980, 9). Where Myers has no reliable figure for total forest area, FAO/UNEP estimates of closed forest or natural woody vegetation were used as a base to calculate deforestation rates. See other explanatory notes.

[f] "Forest regression" in the 1960s, p. 156.

[g] "Forestlands . . . disappearing each year," 1971, p. 98.

[h] Forest "degraded" each year by shifting cultivation, 1950–80, p. 102.

[j] "Primary forest converted to degraded forest . . . or bushland by shifting cultivation" annually, 1980, p. 162.

[k] "Actual rate of clearing in proposed agricultural lands," 1975–80, p. 83.

[m] "Loss of forest cover," 1961–78, p. 110.

[n] "Forest eliminated," 1966–75, according to Brazilian development office (SUDAM), p. 128.

[p] Estimate of forest "eliminated" by shifting cultivation annually, 1980, p. 71.

[q] "Forest in the central and northern parts . . . declining, primarily through shifting cultivation . . . ," p. 65.

[r] Moist forest "disrupted and impoverished through shifting cultivation" annually, 1980, p. 162.

[s] Net rate in Nandi Forest only, 1966–76, p. 159.

[t] Average of deforestation rates rated by 1980 forest area of each country. This is a measure of average annual deforestation in each continent.

[u] Unweighted average of deforestation rates. This is an indication of the amount of disagreement among sources by continent.

Table 3. Spearman Serial Correlation for Deforestation by Country, According to the FAO *Production Yearbook,* FAO/UNEP, and Myers

	(1)	(2)	(3)	(4)	(5)	(6)
(1) FAO Yearbook deforestation rankings for all countries in Africa, Latin America, and Asia[a]	1.00 (60)[c]	—[f]	—	—	.112 (60)	.124 (19)
(2) FAO Yearbook deforestation rankings, countries with reported change and official data[b]		1.00 (41)	—	—	.095 (37)	.146 (11)
(3) FAO Yearbook deforestation rankings, countries with reported change and official data, Africa and Asia only			1.00 (27)	—	.032 (25)	.085 (10)
(4) FAO Yearbook deforestation rankings, with reported change and official data, excluding Benin, Burundi, Costa Rica, Cuba, El Salvador, Guinea, Jamaica, Kenya, Madagascar, Nepal, Paraguay, Surinam, Togo, Zambia				1.00 (23)	.658[e] (23)	.636[d] (9)
(5) FAO/UNEP deforestation rankings					1.00 (61)	.641[e] (20)
(6) Myers deforestation rankings						1.00 (20)

Sources: Myers 1980; FAO 1980a; FAO/UNEP 1982a, 1982b, 1982c.

[a] The countries included in this analysis are Angola, Benin, Burundi, Cameroon, Central Africa Republic, Congo, Ethiopia, Gabon, Gambia, Ghana, Guinea, Ivory Coast, Kenya, Liberia, Madagascar, Mozambique, Nigeria, Rwanda, Sierra Leone, Somalia, Sudan, Tanzania, Togo, Zaire, Zambia, Bangladesh, Brunei, Burma, Kampuchea, India, Indonesia, Laos, Malaysia, Nepal, Philippines, Sri Lanka, Thailand, Vietnam, Bolivia, Brazil, Colombia, Ecuador, Mexico, Paraguay, Venezuela, Belize, Costa Rica, Cuba, Dominican Republic, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Nicaragua, Panama, Peru, Surinam, and Trinidad and Tobago.

[b] Of the 60 countries in the analysis above, the following were excluded because they had no reported change in forest area or unofficial data: Angola, Cameroon, Central African Republic, Gabon, Ghana, Mozambique, Nigeria, Sudan, Tanzania, Kampuchea, Colombia, Venezuela, Guyana, Honduras, Panama, Peru, and Trinidad and Tobago.

[c] Figures in parentheses are the number of countries used to calculate the coefficient.

[d] Significant at the .05 level.

[e] Significant at the .001 level.

[f] Blank indicates cases not tested.

(Kartawinata 1979, 129–30; World Bank 1978, 19). More important, controlled and uncontrolled timber harvesting involve the construction of roads, often in previously impenetrable forest. These roads are an indirect cause of deforestation because they provide access for agricultural populations in search of new land to clear and farm.

Fuel

In addition to commercial timber for export, forests in developing countries provide wood fuels for local populations. Fuelwood and charcoal are widely used for domestic cooking and heating. In many parts of Africa, wood fuels account for as much as 95 percent of total energy use, including energy for small industries such as brewing, baking, and brickmaking (Cecelski et al. 1979; Dunkerley et al. 1981, 48–57). The demand for wood energy has been augmented by the recent dramatic increases in oil prices, which have prevented the switch to non-wood-based fuels. Such use of woodlands and forests—including forest reserves—by growing populations in search of wood fuels is one of the most commonly cited causes of deforestation (Allen 1983; Earl 1975; Eckholm 1976, 39; Jennings 1979, 149; Kolawole 1975; Mikesell 1960; Ranganathan 1979, 14–15; Zambia Forest Department 1978, 6).

Burning and Grazing

Deforestation may occur in ways other than outright clearing or wood removal. The practice of annual burning in many areas prevents forest regrowth (FAO 1980c, 2–5), and grazing by sheep, goats, and cattle has much the same effect (Mikesell 1960; Ranganathan 1979, 14–15; FAO 1980c, 2–5; World Bank 1978, 34). Grazing, plowing, or simply clearing the forest may lead to erosion or may compact the soil, thus reducing its productivity and natural regenera-

tive capacity (Eckholm 1976, 39; Nkoma and Asman 1979, 5–6; Winterbottom 1980, 5).

Forest Management

Forestry departments in developing countries in many cases are not equipped to deal with deforestation and its consequences. The principles of forest management, especially extensive forest management for sustained yields, are unfamiliar to many developing countries where the policy emphasis has been on protection rather than production (Allen 1983). Even where forest management practices are well known, institutions for forest management are poorly supported or nonexistent (World Bank 1978, 35). The problem is compounded when local people for various reasons do not cooperate with forest management schemes (World Bank 1978, 34). Lack of local cooperation may be a symptom of poorly designed policy or an indication that rural people have other development priorities. In any case, to be effective, forestry policy in developing countries must address the complicated reasons for deforestation.

A Panel Analysis of Deforestation, 1968–78

A cross-national study was undertaken in order to shed some light on the complex links between deforestation and its hypothesized causes. The research design is a panel analysis of developing countries for the 1968–78 period. The data represent virtually all the developing countries with per capita gross national product (GNP) less than $3,000 and forest area greater than 5 percent of total land area. The practical impact of using cross-national data is that deforestation rates can be predicted as a function of wood use, socioeconomic development, and land use variables. The reason for a panel analysis design is that deforestation must be measured over time, and the FAO *Production Yearbook* (published annually) is the only source containing developing country forest and woodland data that go back at least five years. The yearly data published by the FAO show little change from year to year, so time series analysis is impossible. Instead, because most developing countries do show a change in forest area over a ten-year time span, a panel analysis that measures change between two points in time is the most appropriate statistical procedure for the analysis of deforestation.

The variables in the analysis include measures of deforestation, wood use, socioeconomic development, and land use (see Table 4). These variables cover most of the major causes of deforestation that have been cited in the literature. Unfortunately data are difficult to obtain for other possible causes of deforestation, which would include livestock density or government expenditures on forestry.

Deforestation Variables

The dependent variable, deforestation, is defined as a negative change in forest area according to FAO *Production Yearbook* figures over the period 1968–78. The FAO definition of forest and woodland refers to natural or planted stands of trees, whether productive or not, and includes land that has been cleared but will be reforested in the foreseeable future (FAO 1980a, 3). As mentioned above, we used these data because the definition of forest appeared to encompass most forms of woody vegetation upon which people in developing countries rely. During the 1968–78 period forest area for the developing countries in the panel analysis declined at an average annual rate of 0.7 percent. The following analysis examines some of the reasons for this deforestation trend.

Socioeconomic Indicators

Data on socioeconomic development are available from publications of the World Bank (1979; 1980a, 108–66; 1980b, 30–269). GNP and population are the socioeconomic development measures included in the deforestation analysis. Both population and per capita GNP grew at an average annual rate of more than 2 percent for the countries in the sample. Because high rate of population growth is one of the most frequently cited causes of deforestation, we hypothesize that the coefficient relating population growth to change in forest area should be negative. Likewise, because economic growth is associated with a switch to commercial fuels, GNP growth should take pressure off the forests and

Table 4. Means and Standard Deviations for Variables in the Analysis

	1968		1978		Average annual change 1968–78[a]		
	Mean	SD	Mean	SD	Mean	SD	Source
Land use							
Percent forest area (of total land area)	36.84	19.39	34.62	19.16	−0.71	1.15	FAO (1978a)
Percent arable land	14.04	13.31	15.31	13.78	1.20	1.62	FAO (1980a)
Percent permanent crops	2.93	3.54	3.35	4.05	1.29	1.68	FAO (1980c)
Socioeconomic development							
Population density, persons per square kilometer	70.1	95.2	87.7	121.6	2.61[b]	0.70	World Bank (1979, 1980a, 1980b)
GNP, US dollars per capita	264	199	639	479	2.27[c]	1.63	World Bank (1980a)
Wood exports, roundwood cubic meters per 1,000 persons	61	184	54	210	−0.45	3.86	FAO (1978b, 1980b)
Wood fuel production, fuelwood and charcoal production, cubic meters per 1,000 persons	665	385	628	383	NA[d]	NA[d]	FAO (1978b, 1980b)
Total wood use (wood exports plus wood fuel production), cubic meters per 1,000 persons	726	445	683	433	−0.29	4.02	FAO (1978b, 1980b)

[a] Average annual percent change rates (*Y*) are calculated by dividing 1978 levels by 1968 levels, subtracting 1 from the result, and then dividing by 10 (the number of years):

$$Y = \frac{\dfrac{\overline{X}_{1978}}{\overline{X}_{1968}} - 1}{10}$$

[b] World Bank data for annual change from 1970–78.
[c] World Bank data for annual change from 1960–70.
[d] Country wood fuel data were quite variable, so means and standard deviations are misleading.

should therefore relate positively to change in forest area.

Land Use Data

The land use variables are from the FAO *Production Yearbook* (FAO 1980a, 3, 45–47; 1980c, 2–50), and they include arable land and land under permanent crops. Arable land is defined as land under annual crops (such as rice, wheat, and corn) and land that is temporarily fallow or meadowland. Permanent crops occupy the land for longer periods of time and include cocoa, coffee, rubber, nuts, and others. Whereas forest area declined during the 1968–78 period, arable land increased at a mean annual rate of 1.2 percent for the developing countries in the sample. As the expansion of agriculture in connection with population growth is a commonly cited cause of deforestation, we would expect that change in arable land would relate negatively to change in forest area. By contrast, since plantation crops cover such a small fraction of total land area, no significant relationship is expected between area under permanent crops and forest area.

Wood Use Data

The measurements of wood use are taken from the FAO *Yearbook of Forest Products* (FAO 1978b; 1980b, 79–88).[1] A measure of total wood production was constructed from the sum of wood exports and wood fuel consumption. The three-year averages for exports (for 1966–68 and 1976–78) were used to construct the total wood production index because of yearly fluctuations in roundwood exports. Per capita wood production for fuelwood use and for export in all developing countries did not change much during the 1968–78 decade, but wood exports in some countries increased by several orders of magnitude. If population and therefore wood demand are growing faster than wood supply, per capita wood supply will decrease with decreasing forest area, and wood production

should be related negatively to change in forest area. Compared to clearing for permanent agriculture, which removes the forest immediately, intensive wood harvesting will result in deforestation only if it affects the regenerative capacity of forests and woodland. Deforestation caused by intensive wood harvesting should therefore take a longer period of time than deforestation caused by the expansion of agricultural land.

Results

Two regression models are used to analyze the relationship between deforestation and the socioeconomic development, land use, and wood production variables. The first model estimates change in forest areas as a function of population growth, change in arable land, GNP growth, and change in wood production. The second model is an analysis of the impact of 1968 cross-sectional variables—including wood production, GNP, population density, and area under permanent crops—on change in forest area during the subsequent decade. Because deforestation rates have been higher in Asia and Africa than in Latin America, the results are reported for two samples: Sample 1 includes Africa, Asia, and Latin America (39 countries) and Sample 2 includes Africa and Asia (25 countries).

Population Growth and Deforestation

The first equation is a short-run model that relates forest area change to changes in population, arable land, GNP, and wood use:[2]

$$Y_1 = a_1 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + e \quad (1)$$

where Y_1 = annual change in forest area, 1968–78,
X_1 = annual population growth rate 1970–78,
X_2 = annual change in cultivated land areas, 1968–78,
X_3 = annual per capita GNP growth rate, 1960–78, and
X_4 = annual change in per capita wood fuels production and roundwood export, 1968–78.

The significant coefficients in Equation (1) can be interpreted as reflecting short-run relationships; for instance, a change in forest area over the decade is related to a change in other variables for roughly the same time period.

The results shown in Table 5 indicate that an increase in population is associated with a loss of forest area. The coefficients relating population change to forest area change ($b_1 = -.005$, $-.008$ for Samples 1 and 2, respectively) are negative and significant at the .10 and .05 levels, respectively. The negative coefficients in the regression (b and beta) and the negative correlation coefficients (r) mean that developing countries with high rates of population growth also have higher-than-average rates of deforestation. In addition, the coefficient for the sample of Asian and African countries is stronger than for the total sample, suggesting that in Latin America population growth may not be as important a factor in deforestation as it is in Asian and African countries.

Population growth in connection with expansion of arable land has been regarded as one of the contributors to deforestation. However, the coefficient for change in arable land (b_2 = .140, $-.220$ for Samples 1 and 2, respectively), although negative, is not significant. The lack of a direct relationship in the multivariate analysis between deforestation and agricultural expansion (i.e., b_2 is not significant in Table 5) can be explained through an examination of the bivariate correlations between change in cropland, forest area, and population (see Table 6). Changes in forest area and arable land are negatively correlated for both samples ($r = -.212$, $-.380$), and both simple correlations are stronger than are the multivariate coefficients, probably because forests are being replaced by agriculture. Changes in cropland and population are positively and quite strongly correlated (r = .352, .580). The bivariate correlation coefficients in Table 6 indicate that population growth is related to agricultural expansion, which in turn is related to forest loss. This relationship does not show up in the multivariate analysis because controlling for population suppresses the negative correlation between cropland and change in forest area. We conclude that both population growth and change in arable land are associated with deforestation. The patterns also are much stronger in Asia and Africa than in Latin America.

Whereas the often-cited cycle of population growth, expansion of cultivated land, and deforestation is confirmed by the analysis, the cor-

Table 5. The Relationship Between Forest Area Change and Change in Population Growth, Cultivated Area, Per Capita GNP, and Wood Fuels for Asian, African, and Latin American Countries, 1968–78 (Model 1)

	Y_1 Forest area change, 1968–78 (countries with reported change)					
	Africa, Asia, and Latin America			Africa and Asia		
Independent variables	b[d]	Beta[e]	Pearson's r[f]	b[d]	Beta[e]	Pearson's r[f]
X_1 Annual population growth rate 1970–78	−.005 (1.477)[ab]	−.255	−.291	−.008 (1.785)[c]	−.406	−.492
X_2 Annual cultivated land change, 1968–78	−.140 (.734)	−1.26	−.221	−.220 (.722)	−.166	−.380
X_3 Annual per capita GNP growth rate, 1960–78	.0009 (.699)	.113	.097	−.0003 (.187)	−.036	−.020
X_4 Annual change in per capita wood fuels production and roundwood exports, 1968–78	−.007 (.141)	−.023	−.059	.008 (.148)	.029	−.019
Constant	.0042			.014		
Number of countries		39			25	
F Statistic		1.091			1.790	
R^2		0.113			0.263	

[a] Figures in parentheses are t-statistics.
[b] Significant at the .10 level.
[c] Significant at the .05 level.
[d] Coefficient of variable in regression model (Equation (1)).
[e] Adjusted coefficient of variable in regression model (Equation (1)).
[f] Simple correlation between dependent variable (forest area) and each independent variable (X_1, X_2, X_3, or X_4) for sample.

responding hypothesis that per capita GNP should relate positively to change in forest area is not supported. Nor is the per capita wood production variable significant in the equations in either sample. In order for wood production to cause deforestation, the rate of harvesting of trees has to exceed the rate of natural regeneration or reforestation. Deforestation in this sense is really a gradual but cumulative decrease in standing forest volume. Obviously, this process requires a longer time to show up than does the outright clearing of land for farming. Therefore the second model examines the long-term relationships between deforestation and a similar set of variables.

Wood Use and Deforestation

Harvesting forests for fuelwood and wood export may have a delayed impact on the rate of deforestation. The regrowth of trees requires a minimum of five years for fast growing species and up to 100 years or more for some hardwoods (National Academy of Sciences 1980, 72–161). Thus, when small trees are cut down for fuelwood or when trees are harvested for export with no replanting, the impact might appear only after the next ten or more years. The second regression model is specified to capture this delayed impact:[3]

$$Y_1 = a_1 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + e \quad (2)$$

where Y_1 = decade change in forest area, 1968–78 (log forest area, 1978 − log forest area in 1968),
X_1 = log percent forest area in 1968,
X_2 = population density in 1968,
X_3 = per capita GNP in 1968,
X_4 = per capita wood fuels consumption and wood exports in 1968, and
X_5 = percent land area under plantation crops in 1968.

The b coefficients in this equation indicate the relationship between the change in forest area over the 1968–78 period and the 1968 levels of forest area, population density, per capita GNP, per capita wood use, and percent area under permanent crops.

The coefficient b_4 indicates whether the level of wood production in 1968 is negatively or pos-

Table 6. Correlation Matrix For Variables in the Deforestation Analysis (28 Countries)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Forest change 1968–78 (1)	1.00	−0.412	−0.495	−0.097	0.010	−0.194	−0.275	−0.203	−0.320	−0.379	−0.178	−0.268	−0.262
Arable land change 1968–78 (2)		1.00	0.529	−0.065	−0.189	0.085	0.133	0.045	0.126	0.169	−0.034	−0.083	0.185
Population growth 1970–77 (3)			1.00	−0.046	−0.179	0.247	0.320	0.258	0.345	0.427	0.257	0.438	−0.093
GNP per capita growth 1960–78 (4)				1.00	0.506	−0.296	−0.190	0.256	0.183	−0.053	0.680	0.466	0.256
Percent forest area 1978 (5)					1.00	0.005	0.008	0.401	0.378	0.201	0.534	0.455	0.183
Woodfuels consumption per capita 1978 (6)						1.00	0.933	−0.23	0.094	0.775	−0.182	−0.006	−0.311
Woodfuels consumption per capita 1968 (7)							1.00	0.033	0.159	0.860	−0.053	0.149	−0.249
Wood export per capita 1977 (8)								1.00	0.907	0.268	0.520	0.536	0.268
Wood export per capita 1967 (9)									1.00	0.639	0.532	0.608	0.245
Woodfuels and exports per capita (10)										1.00	0.233	0.430	−0.067
GNP per capita 1978 (11)											1.00	0.927	0.145
GNP per capita 1968 (12)												1.00	0.106
Percent plantation crops 1968 (13)													1.00

itively related to deforestation from 1968 to 1978. The results in Table 7 show that change in forest area over the 1968–78 decade is negatively related to wood use. The b_4 coefficients (−.0001 and −.0001 for Samples 1 and 2, respectively) are significant at the .05 level (see Table 7) indicating that forest loss, or deforestation, increases with increasing wood use. Since according to FAO figures the norm in developing countries for the 1968–78 period is a loss of forest area, this result means that developing countries with high levels of per capita wood fuels consumption and wood exports in 1968 experienced a greater-than-average loss of forest area sometime during the subsequent decade. Thus, deforestation over the longer term is more severe in countries with high levels of wood use.

The rationale for summing per capita wood exports and wood fuels is that in different geographic regions deforestation can be caused by quite different kinds of wood use. In the semiarid tropics with little forest area, one would expect that deforestation would be caused by excessive consumption of wood fuels. On the other hand, in the tropics where forests are abundant, wood export may be the cause of deforestation. It is also true that wood exporting countries have higher area under forest area and higher GNP per capita than countries where the dominant wood use is for fuel.[4] Thus, adding wood exports to wood fuel consumption yields a more general indicator of wood harvesting that is applicable both to countries with tropical moist forests and to countries with mostly semi-arid woodlands. Wood use taken as the sum of these two variables is more closely related to deforestation than is either wood fuels production or wood exports alone.

Neither GNP nor population density in 1968 is significantly related to the subsequent change in forest area. However, the b_1 coefficients for log of percent of forest area are positive and significant at the .10 and .05 levels for Samples 1 and 2, respectively, indicating that countries with less-than-average forest resource bases in 1968 are more likely to lose forest area during the next ten years. The percent of land area under plantations has a negative relationship to change in forest area, significant at the .01 level for both samples. This is a rather surprising finding since most of the literature on land use attributes deforestation to change in agricultural as opposed to plantation land. Plantation crops such as tea, coffee, cocoa, bananas, sisal, and others are important sources of revenue to developing countries, but they cover a relatively small fraction of the area of the countries in our analysis (Lanly and Clement 1979). Therefore, we would not like to speculate as to whether this

Table 7. The Relationship Between Forest Area Change and Population Density, Per Capita GNP, and Wood Production for Asia, Africa, and Latin America, 1968–78 (Model 2)

	Y_2 Forest area change, 1968–78 (countries with reported change)					
	Africa, Asia, and Latin America			Africa and Asia		
Independent variables	b[d]	Beta[e]	Pearson's r[f]	b[d]	Beta[e]	Pearson's r[f]
X_1 Log percent forest area, 1968	.045 (1.337)[ab]	.207	.193	.078 (1.832)[c]	.332	.094
X_2 Population density, 1968	.0013 (.529)	.091	.061	−.0005 (.207)	−.040	.166
X_3 Per capita GNP, 1968	.0001 (.932)	.147	.198	.0000 (.000)	−.003	−.095
X_4 Per capita wood fuels and wood exports, 1968	−.0001 (2.204)[c]	−.360	−.335	−.0001 (2.976)[c]	−.585	−.550
X_5 Percent land area under plantation crops (e.g., tea), 1968	−.016 (2.791)[c]	−.415	−.378	−.018 (2.573)[c]	−.441	−.400
Constant	−.144			−.167		
Number of countries		39			25	
F Statistic		3.614[c]			3.856[c]	
R^2		.353			.503	

[a] Figures in parentheses are t-statistics.
[b] Significant at the .10 level.
[c] Significant at the .05 level.
[d] Coefficient of independent variables in multivariate model (Equation (2)).
[e] Adjusted coefficient in multivariate model.
[f] Correlation.

correlation is caused by an unknown third variable or whether forests and woodlands are being converted into plantations.

Discussion and Conclusion

In summary, the statistical panel analysis confirms that deforestation (measured as the rate of loss of forest area) is significantly related to population growth, agricultural expansion, and the past rate of wood production in a sample of 28 developing countries from Africa, Asia, and Latin America. Countries with high population growth, rapid expansion of agriculture, and high levels of wood production (for domestic and foreign markets) had higher-than-average rates of deforestation over the period 1968–78. These results support the major hypotheses in the literature. According to the available sources, deforestation—the loss of natural closed forest and forestland area—is a common phenomenon in developing countries. This trend does not include forest plantations, which, however, represent only a small fraction of total forest area in developing countries. Deforestation is associated in the short term with rising population and expansion of agriculture and in the long term with wood harvesting for fuel and export. Deforestation through extensive wood use does not occur as quickly as it does through population growth and expansion of arable land. Intensive wood harvesting does result, however, in deforestation; a country that has high wood production and high wood exports tends to lose forest area within about a decade. The delayed appearance of net deforestation might be due to the gradual, cumulative effect of exceeding sustainable yields in forests and woodlands. Some developing countries are now harvesting wood at such a rate that, without reforestation, the consequence will be a future loss of forest area.

Many of the perceived disastrous consequences of deforestation arise directly from two opposing interpretations of the role of forestry in developing countries. One view sees deforestation as a natural, beneficial component of economic development; in the other view, deforestation implies an ever-worsening resource base that hinders the process of development. According to some, deforestation in developing countries is nothing more than the gradual human alteration of an abundant natural resource

(land) in order to increase productivity and welfare. Thus formerly uninhabited forests are gradually cleared, providing wood for export and domestic consumption, and the land comes under the hoe and plow to produce food or is converted to forest plantations for continued wood production, depending on demand (see Castle 1982; Clawson 1981; Sedjo n.d.; Simon 1981, 1982). According to the opposing interpretation, deforestation occurs because factors beyond an individual's or nation's control force overexploitation and destruction of the natural resource base, thereby inhibiting or vitiating the process of development (see Daniel and Kulasingan 1974; Eckholm 1975, 1982a, 1982b; Fearnside 1982; Gomez-Pompa, Vasques, and Guevara 1972; Hecht 1982; Kartawinata 1979; Myers 1976, 1980, 1982, 1983; Nordin and Meade 1981; Pires and Prance 1977). These authors point out that high oil prices prevent the poor from substituting oil for wood fuels while insignificant gains in agricultural productivity require that more land be cleared to feed growing populations. The resulting disappearance of forests reduces agricultural and forest productivity and social welfare.

These two views are helpful in conceptualizing both the constructive and destructive aspects of deforestation, but they oversimplify a complex reality. It should be remembered that the consequences of deforestation are to a great extent location-specific. It is extremely difficult to infer the losses—be they of species diversity, wood production potential, soil fertility, or watershed protection—from an analysis of the overall rate of deforestation. Nevertheless, these factors determine the severity of the impact of forest loss on the quality of life in developing countries. Deforestation of tropical moist forests in Zaire, Indonesia, and Brazil has resulted in soil nutrient loss and low productivity grazing, forestry, and agriculture. Deforestation causes hardships for rural populations in the arid and semi-arid countries such as Niger and Upper Volta because it increases scarcity of wood, forage, and food and depresses agricultural yields. Deforestation in a mountainous country such as Nepal can cause serious environmental problems including accelerated hillslope erosion and sediment delivery to river channels. On the other hand, tropical moist forests, if managed properly, might well have the potential for supplying much of the world with timber and other forest products (Earl 1975; Pires 1978; Myers 1984). Conversion of forests to agriculture might not be destructive at all if the farm land, fallow, and marginal lands were properly managed; many farming systems can combine food cropping with wood energy production and environmental protection (Dunkerley et al. 1981; Eckholm 1979; Ranganathan 1979).

The recent controversy over deforestation serves to bring the forestry sector and forestry policy under closer scrutiny. In the past ten years, both the funding and the range of forestry policy options have expanded significantly. Developing countries in cooperation with donor agencies have developed programs responsive to international pressures (such as for the preservation of unique forest ecosystems), national priorities (such as revenue from wood exports or expanded domestic agricultural production), and to local demand for wood energy, poles, and other forest products (Barnes and Allen 1982; Hammer 1983; Skutsch 1983). But the results of these efforts have been mixed. Forest reserves suffer from illegal cutting and grazing; forest plantations are hampered by lack of knowledge regarding soil conditions, rainfall requirements, and appropriate species. In spite of these difficulties, beneficial programs have been implemented. Examples include community woodlots for woodfuels and other forest products, tree plantations along roadsides, canal banks and other locations, smallholder tree farms to provide feedstock for electricity generation, tree seedling distribution, and other activities. The ultimate outcome of deforestation depends on these programs, which in turn require proper site selection, careful species choice, adequate forestry extension services, and local and international commitments to reforestation.

Acknowledgment

The research for this study was funded under Cooperative Agreement No. AID/DSAN-CA-0179 established between Resources for the Future and the U.S. Agency of International Development, Office of Energy, for a program of energy policy studies for developing countries. We would like to thank William Ramsay and Joy Dunkerley for their encouragement and support for this project. For their valuable comments on an earlier draft of this paper, we thank Roger Sedjo, Clifford Russell, and Jeff Vaughan. We also appreciate the help of Elizabeth Shue who provided very valuable research assistance for the project.

Notes

1. Throughout the analysis wood fuel production is assumed to equal consumption in each country, and the terms will be used interchangeably throughout this paper. This is because very little fuelwood or charcoal is traded internationally. In 1978 only 12 percent of world exports of fuelwood and charcoal came from developing countries (Sri Lanka, the Philippines, Indonesia, Thailand, Brazil, and the Sudan) and less than 6 percent of these exports go to developing countries (Malaysia). Exports of fuelwood and charcoal from these countries represented only .06 percent of their production of fuelwood and charcoal (FAO 1980b, 83–84; U.N. Statistical Office 1980, 6, 566–67).
2. The variables are all for the 1968–78 period with the exception of the World Bank data. The World Bank data starting points are 1970 and 1960, and they are based on annual data. The FAO annual change rates have been calculated by dividing the log of the percent 1968–78 change (the ratio of land area or wood production in 1978 to 1968) by ten.
3. The panel model is a particular form of cross-section, cross-time analysis (see Kessler and Greenberg 1981). This specific model is recommended by Jackman (1980, 606). The dependent variable is a decade percent change in forest area, as is the case in the previous equation. However, the log of percent forest area in the base period is included as a control variable for both methodological and substantive reasons. It is necessary to control for the base period because even a constant rate of growth over a given period will result in successively larger absolute increments, as a function of the steadily increasing base. But this control variable can also be interpreted substantively. It indicates how a larger or smaller percent area under forest in the base period affects subsequent rates of change in forest area.
4. For the total sample the Pearson's correlation coefficient between 1978 wood exports and 1978 percent area under forests is positive at .244 (significant at .067), and wood exports also relate positively to per capita GNP at .413 (significant at .001).

References

Allen, J. C. 1983. Deforestation, soil degradation, and wood energy in developing countries. Ph.D. dissertation, Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore.

Barnes, D. F., and Allen, J. C. 1982. Social forestry in developing nations. Discussion paper D-73F, Resources for the Future, Washington, D.C.

Barney, G. O., ed. 1980. *Global 2000 report to the President. Entering the twenty-first century*. Vol. 2: Technical Report. Report prepared by the Council on Environmental Quality and the Department of State. Washington, D.C.: U.S. Government Printing Office.

Bazilevich, N. E.; Rodin, L. F.; and Rozov, N. N. 1971. Geographical aspects of biological productivity. *Soviet Geography Review Translation* 12:293–317.

Bennett, C. F. 1979. Some social and economic consequences of and constraints to the use of forests for energy and organics in Canada, the United States of America, and Los Estados Unidos de Mexico. In *Biological and sociological basis for a rational use of forest resources for energy and organics,* ed. Stephen G. Boyce. Proceedings of an international workshop sponsored by the Man and the Biosphere Committees of Canada, Mexico, and the United States, 6–11 May, at Michigan State University, East Lansing.

Brokensha, D., and Riley, B. 1978. Forest, foraging, fences and fuel in a marginal area of Kenya. Paper presented at a USAID Africa Bureau Firewood Workshop, 12–14 June, Washington, D.C.

Brüning, E. F. 1971. Forstliche produktionslehre. *Europaische Hochschulschriften* (Bern) 25(1).

———. 1975. Okosyteme in den Tropen. *Umschau* 74:405–10.

Castle, E. 1982. Resource adequacy, global development, and international relations. Paper presented at the annual meeting of the American Association for the Advancement of Science, 8 January, Washington, D.C.

Cecelski, E.; Dunkerley, J.; Ramsay, W.; and Mbi, E. 1979. *Household energy and the poor in the Third World*. Research paper R-15. Washington, D.C.: Resources for the Future.

Clawson, M. 1981. Entering the 21st century: The Global 2000 report to the President. *Resources* 66:19–21.

Daniel, J. C., and Kulasingan, A. 1974. Problems arising from large-scale forest clearing for agricultural use: The Malaysian experience. *Malaysian Forester* 37(3):152–60.

Dunkerley, J.; Ramsay, W.; Gordon, L.; and Cecelski, E. 1981. *Energy strategies for developing nations*. Baltimore: Johns Hopkins University Press for Resources for the Future, Inc.

Earl, D. E. 1975. *Forest energy and economic development*. Oxford: Clarendon Press.

Eckholm, E. 1975. *The other energy crisis: Firewood*. Worldwatch paper no. 1. Washington, D.C.: Worldwatch Institute.

———. 1976. *Losing ground: Environmental stress and world food prospects*. Worldwatch Institute with the support and cooperation of the United Nations Environment Program. New York: W. W. Norton and Co.

———. 1979. *Planting for the future: Forestry for human needs*. Washington, D.C.: Worldwatch Institute.

———. 1982a. Human wants and misused lands. *Natural History* 91(6):33–48.

———. 1982b. *Down to earth: Environment and human needs*. New York: W.W. Norton for the International Institute for Environment and Development.

Eyre, S. R. 1978. *The real wealth of nations*. New York: St. Martin's Press.

Fearnside, P. W. 1982. Deforestation in the Brazilian

Amazon: How fast is it occurring? *Interciencia* 7(2):82–88.

Food and Agriculture Organization of the United Nations. 1963, *World forest inventory*. Rome: FAO.

———. 1966. *1965 production yearbook*. Vol. 9. Rome: FAO.

———. 1978a. *1977 production yearbook*. Vol. 31. Rome: FAO.

———. 1978b. *1976 yearbook of forest products, 1965–1976*. Rome: FAO.

———. 1980a. *1979 production yearbook*. Vol. 33. Rome: FAO.

———. 1980b. *1979 yearbook of forest products, 1967–1979*. Rome: FAO.

———. 1980c. *The state of food and agriculture 1979*. World Review of Forestry and Rural Development, FAO Agriculture Series no. 10. Rome: FAO.

FAO and U.N. Environment Program. 1982a. Proyecto de evaluacion de los recursos forestales tropicales (en el marco de SIMUVIMA)—los recursos forestales de la America tropical. Primera parte: Sintesis regional. Prepared by J. P. Lanly. Rome: FAO.

———. 1982b. Tropical forest resources assessment project (in the framework of GEMS)—forest resources of tropical Africa. Part I: Regional synthesis. Prepared by J. P. Lanly and Y. S. Rao. Rome: FAO.

———. 1982c. Tropical forest resources assessment project (in the framework of GEMS)—forest resources of tropical Asia. Part I: Regional synthesis. Prepared by J. P. Lanly and Y. S. Rao. Rome: FAO.

Gomez-Pompa, A.; Vasques, C.; and Guevara, S. 1972. The tropical rainforest: A non-renewable resource. *Science* 177:762–69.

Hammer, T. 1983. Reforestation and community development in the Sudan. Discussion paper D-73M, Resources for the Future, Washington, D.C.

Hecht, S. 1982. Cattle ranching development in the eastern Amazon: Evaluation of a development policy. Ph.D. dissertation, Department of Geography, University of California, Berkeley.

Houghton, R. A.; Hobbie, J. E.; Melillo, J. M.; Moore, B.; Peterson, B. J.; Shaver, G. R.; and Woodwell, G. M. 1983. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: A net release of CO_2 to the atmosphere. *Ecological Monographs* 53(3):235–62.

Huntley, B. J., and Walker, B. H. 1982. *Ecology of tropical savannas*. New York: Springer-Verlag.

Jackman, R. 1980. A note on the measurement of growth rates in cross-national research. *American Journal of Sociology* 86:604–17.

Jennings, P. 1979. Dry forests of the Dominican Republic and their energy production capacity. In *Biological and sociological basis*. (See Bennett 1979.)

Kartawinata, K. 1979. An overview of the environmental consequences of tree removal from the forest in Indonesia. In *Biological and sociological basis*. (See Bennett 1979.)

Kessler, R., and Greenberg, D. 1981. *Linear panel analysis*. New York: Academic Press.

Kolawole, M. 1975. Economic aspects of flue-cured tobacco production in the Savanna Zone of Western Nigeria. *Savanna* 4(1):50–56.

Lanly, J. P., and Clement, J. 1979. Present and future forest and plantation areas in the tropics. Miscellaneous paper, FAO, Rome.

Lieth, H. 1972. Uber die primerproduktion der pflanzendecke der erde. *Angewandte Botanik* (Berlin) 46:1–37.

———. 1979. Forest uses in global and regional (USA) perspectives. In *Biological and Sociological basis*. (See Bennett 1979.)

Lieth, H., and Whittaker, R. H. 1975. *Primary productivity of the biosphere*. New York: Springer-Verlag.

Lugo, A. E., and Brown, S. 1982. Conversion of tropical moist forests: A critique. *Interciencia* 7(2):89–93.

Margaris, N. S. 1979. Can we harvest Mediterranean-type ecosystems to obtain energy and organics? In *Biological and sociological basis*. (See Bennett 1979.)

Marsh, G. P. 1874. *Man and nature: The Earth as modified by human action*. New York: Scribner Armstrong and Co.

Mikesell, M. 1960. Deforestation in Northern Morocco. *Science* 132:441–47.

Mnzava, E. M. 1980. Report on village afforestation: Lessons of experience in Tanzania. FAO, Rome.

Myers, N. 1976. An expanded approach to the problem of disappearing species. *Science* 193:198–202.

———. 1980. *Conversion of tropical moist forests*. A report prepared for the Committee on Research Priorities on Tropical Biology of the National Research Council. Washington, D.C.: National Academy of Sciences.

———. 1982. Room in the ark? *Bulletin of the Atomic Scientists* 38(9):44–48.

———. 1983. Tropical moist forest: Over exploited and under-utilized? *Forest Ecology and Management* 6:59–79.

———. 1984. *The primary source: Tropical forests and our future*. New York: W.W. Norton and Co.

Myers, N., and Myers, D. 1982. From the duck pond to the global commons: Increasing awareness of the supranational nature of emerging environmental issues. *Ambio* 11(4):195–201.

National Academy of Sciences. 1980. *Firewood crops: Shrubs and tree species for energy production*. Report of an ad-hoc panel of the Committee on Technology Innovation. Washington, D.C.

Nkoma, J. S., and Asman, S. J. 1979. Reflections on energy with some reference to Tanzania. Proceedings of the International Workshop on Energy and Environment in East Africa, 7–11 May, held in Nairobi, Kenya by the Royal Swedish Academy of Science.

Nordin, C. F., and Meade, R. H. 1981. Deforestation and increased flooding of the Upper Amazon. *Science* 215:426–27.

Olson, J. S. 1975. *World ecosystems*. Washington, D.C.: Seattle Symposium.

Openshaw, K. 1978. Woodfuel—a time for re-assessment. *Natural Resources Forum* 3(1):35–71.

Persson, R. 1974. *World forest resources: Review of*

the world's forest resources in the early 1970's. Research Notes no. 17. Stockholm: Department of Forest Survey, Royal College of Forestry.

Pires, J. M. 1978. The forest ecosystems of the Brazilian Amazon: Description, functioning and research needs. In *Tropical forest ecosystems: A state of knowledge report*. Paris: UNESCO.

Pires, J. M., and Prance, G. T. 1977. The Amazon forest: A natural heritage to be preserved. In *Extinction is forever*, ed. G. T. Prance and T. S. Elias. New York: New York Botanical Garden.

Powell, J. W. 1978. Wood waste as an energy source in Ghana. In *Renewable energy resources and rural applications in the developing world*, ed. Norman L. Brown. Boulder, Colo.: Westview Press.

Prance, G. T. 1977. The Phytogeographic subdivisions of Amazonia and their influence on the selection of biological reserves. In *Extinction is forever*. (See Pires and Prance 1977.)

———. 1982. *Biological diversification in the tropics*. Proceedings of the Fifth International Symposium of the Association for Tropical Biology, 8–13 February, Macuto Beach, Caracas, Venezuela. New York: Columbia University Press.

Ranganathan, S. 1979. *Agro-forestry: Employment for millions*. Bombay: Tata Press.

Richards, P. W. 1964. *The tropical rain forest: An ecological study*. Cambridge: Cambridge University Press.

Ross-Sheriff, B. 1980. Forestry projections. In *Global 2000 report to the President*, ed. G. O. Barney, ch. 8. (See Barney 1980.)

Schmithüsen, F. 1976. Forest utilization contracts on public land in the tropics. *Unasylva* 28(112–113):52–73.

Sedjo, R. n.d. Global forests. In *The resourceful Earth*, ed. J. Simon and H. Kahn. Oxford: Blackwell, forthcoming.

Simon, J. 1981. *The ultimate resource*. Princeton: Princeton University Press.

———. 1982. Life on Earth is getting better, not worse. Paper presented at the annual meeting of the American Association for the Advancement of Science, 8 January, Washington, D.C.

Skutsch, M. 1983. Why people don't plant trees: The socioeconomic impact of existing woodfuel programs: Village case studies, Tanzania. Discussion paper D-73P, Resources for the Future, Washington, D.C.

Sommer, A. 1976. Attempt at an assessment of the world's tropical moist forests. *Unasylva* 28(112–113):5–24.

Spears, J. 1980. World Bank renewable energy task force study: Developing countries fuelwood supply/demand analysis, 1980–2000. World Bank. Mimeo.

Thirgood, J. V. 1981. *Man and the Mediterranean forest: A history of resource depletion*. New York: Academic Press.

Thomas, W. L., ed. 1956. *Man's role in changing the face of the Earth*. Chicago: University of Chicago Press.

Steele, R. C. 1979. Some social and economic consequences and constraints to the use of forestry for energy and organics in Great Britain. In *Biological and sociological basis*. (See Bennett 1979.)

Uhl, C. 1982. Recovery following disturbance of different intensities in the Amazon rain forest of Venezuela. *Interciencia* 7(1):19–24.

U.N. Statistical Office. 1980. *Yearbook of international trade statistics, 1979*. Volume II, *Trade by commodity, commodity matrix tables*. New York.

U.S. Interagency Task Force on Tropical Forests. 1980. The world's tropical forests: A policy, strategy and program for the United States. Report to the President. Washington, D.C.: U.S. Government Printing Office.

von Wissman, H.; Poech, H.; Smolla, G.; and Kussmaul, F. 1956. On the role of man and nature in changing the face of the dry belt of Asia. In *Man's role* (See Thomas 1956.)

West, D. C.; Shugart, H. H.; and Botkin, D. B. 1981. *Forest succession: Concepts and application*. New York: Springer-Verlag.

Whittaker, R. H., and Likens, G. E. 1973. Primary production: The biosphere and man. *Human Ecology* 1:357–69.

Whittaker, R. H., and Woodwell, G. M. 1971. Measurement of net primary productivity of forests. In *Productivity of forest ecosystems*, ed. P. Duvigneaud. Proceedings of the Brussels Symposium, October, pp. 159–75. Paris: UNESCO.

Windhorst, H. W. 1974. Das ertragspotential der walder der erde. In *Studien zur waldwirtschaft geographic* (Special issue of *Geographischen zeitschrift* 39) (Weisbaden).

Winterbottom, R. 1980. Reforestation in the Sahel: Problems and strategies. Paper presented at the African Studies Association Annual Meeting, 15–18 October, in Philadelphia, Pennsylvania.

Woodwell, G. M.; Hobbie, J. E.; Houghton, R. A.; Melillo, J. M.; Peterson, R. J.; Shaver, G. R.; Stone, T. A.; Moore, B.; and Park, A. B. 1983a. *Deforestation measured by Landsat: Steps toward a method*. Report DOE/EV/10468-1 prepared for the Office of Energy Research, U.S. Department of Energy under Contract No. DE-AC02-80EV10468, June. Washington, D.C.

Woodwell, G. M.; Hobbie, J. E.; Melillo, J. M.; Moore, B.; Peterson, B. J.; and Shaver, G. R. 1983b. Global deforestation: Contribution to atmospheric carbon dioxide. *Science* 222:1081–86.

World Bank. 1978. *Forestry sector policy paper*. Washington, D.C.

———. 1979. World Bank Data Services, data run 18 December.

———. 1980a. *1980 world development report*. Washington, D.C.

———. 1980b. *World tables*. 2d ed. Washington, D.C.

———. 1980c. *Energy in developing countries*. Washington, D.C.

World Ecological Areas Programme. 1980. World Ecological Areas Programme: A proposal to save the world's tropical rainforests. *The Ecologist* (Wadebridge) 10(1–2): 1–2.

Zambia Forest Department, Office of the Chief Conservator of Forests. 1978. Lusaka fuelwood project. Lusaka, Zambia.